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Minimizing Noise-Temperature Measurement Errors

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Minimizing noise-temperature measurement errors of low-noise amplifiers has

$$Y = \frac{(T/L) + (Tn/L) + TL + Te}{(T/L) + TL + Te} \quad (1)$$

and

$$Te = \frac{Te}{(T/L) + TL + Te} - (T/L) - Tn(1 - 1/L) \quad (2)$$

calibrated more accurately by a standards laboratory. The approximate value of L , dB, resulting in the minimum Te -rms measurement error, is indicated for each case, except case 5.

A comparison of cases 1 and 2 with cases 3, 4, and 5 shows that with the accuracies assumed, two loads are

References

- [1] C. Stelzried, *The Deep Space Network—Noise Temperature Concepts, Measurements, and Performance*, JPL Publication 82-33, Jet Propulsion Laboratory,
- [2] C. Stelzried, R. Clauss, W. Rafferty, and S. Petty, "DSN G/T_{op} and Telecommunications System Performance," *TDA Progress Report 42-108*, vol. October–December 1991, Jet Propulsion Laboratory, Pasadena, California, pp. 271–278, February 15, 1991.
- [3] C. Stelzried, "Corrections of High-Frequency Noise-Temperature Inaccuracies," *TDA Progress Report 42-111*, vol. July–September 1992, Jet Propulsion Laboratory, Pasadena, California, pp. 169–277, November 15, 1992.

Table 1. Summary of Supercalc 4 computer programs NOISE1ND and NOISE1LD analysis of an LNA noise-temperature measurement delta or error (DTe).

Case	Figure	Method	Configuration	L , dB	DTe (rms), K
1	3, 4	1 input load and noise source	$T = 300$ K $T_n = 1000$ K $DYG = 0.01$	20	1.0
2	5, 6	1 input load and noise source	$T = 300$ K $T_n = 60,000$ K $DYG = 0.02$	20	1.1
3	7, 8	2 input loads	$T1 = 80$ K $T2 = 300$ K $DYG = 0.01$	10	0.7
4	9, 10	2 input loads	$T1 = 2$ K $T2 = 300$ K $DYG = 0.02$	0	0.3
5	11, 12	2 input loads	$T1 = 2$ K $T2 = 300$ K $DYG = 0.01$	10	0.5

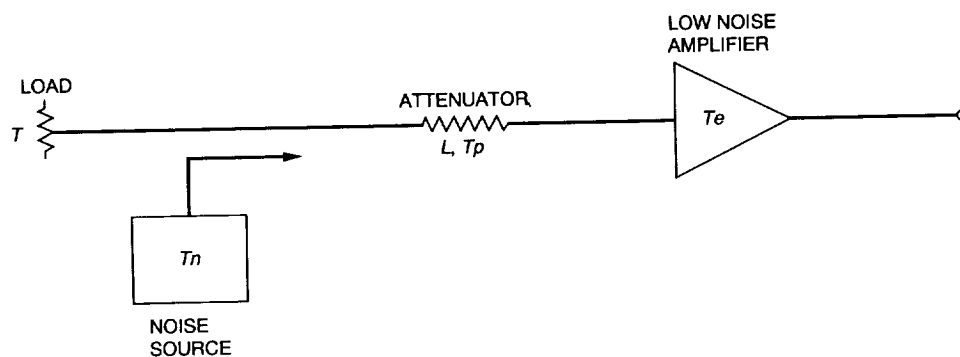


Fig. 1. Low-noise amplifier measurement scheme using a load at temperature T , a noise source, and a fixed attenuator.

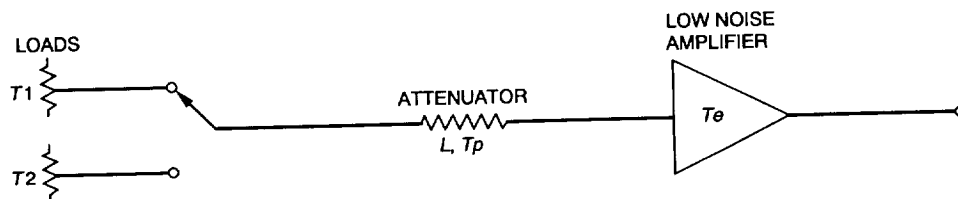


Fig. 2. Low-noise amplifier measurement scheme using two loads at temperatures T_1 and T_2 and a fixed attenuator.

INPUT

T= 300 Tn= 1000 Tp= 2
 DT= .1 DTn= 50 DTP= .1 Te= 4
 DYLDDB,A= .01 DLDB,A= .01 B,MHZ= 50 DYG= .01
 DYLDDB,B= .01 DLDB,B= .03 T,SEC= 1
 L,DB 0 3 10 15 20 23 30
 L 1 1.995 10 31.62 100 199.53 1000

RESULTS

----- Te ERROR,K -----
 DL .013800 .1366 .4133527 .6030 .7862374 .89317 1.1342
 DT .1 .1 .0501 .01 .0032 .001 .00050 .00010
 DTn 50 15.2 7.768 1.79 .7712 .449 .37468 .3149
 DTP .1 0 .0499 .09 .0968 .099 .09950 .0999
 DYL 6.59566 3.356 .7500375 .3047 .1645480 .13678 .16922
 DYN .112082 .0575 .0137455 .0065 .0048182 .00528 .01297
 DYG 7.72680 3.966 .9466179 .4457 .3284142 .35618 .80217
 SUM 29.7483 15.38 4.013754 2.231 1.833018 1.8661 2.5335
 RMS 18.2830 9.347 2.200452 1.122 .9821036 1.0458 1.4380

NOMINAL CALC

TL 0 .9976 1.8 1.937 1.98 1.9900 1.998
 Y 4.28947 4.226 3.793296 3.050 2.113586 1.6688 1.1588
 YDB 6.32404 6.259 5.790167 4.843 3.250199 2.2241 .64001
 Te 4 4 4 4 4 4 4

ERROR CALC

L,DB 01 3 1 10 31 15.46 20.61 23.7 30.91

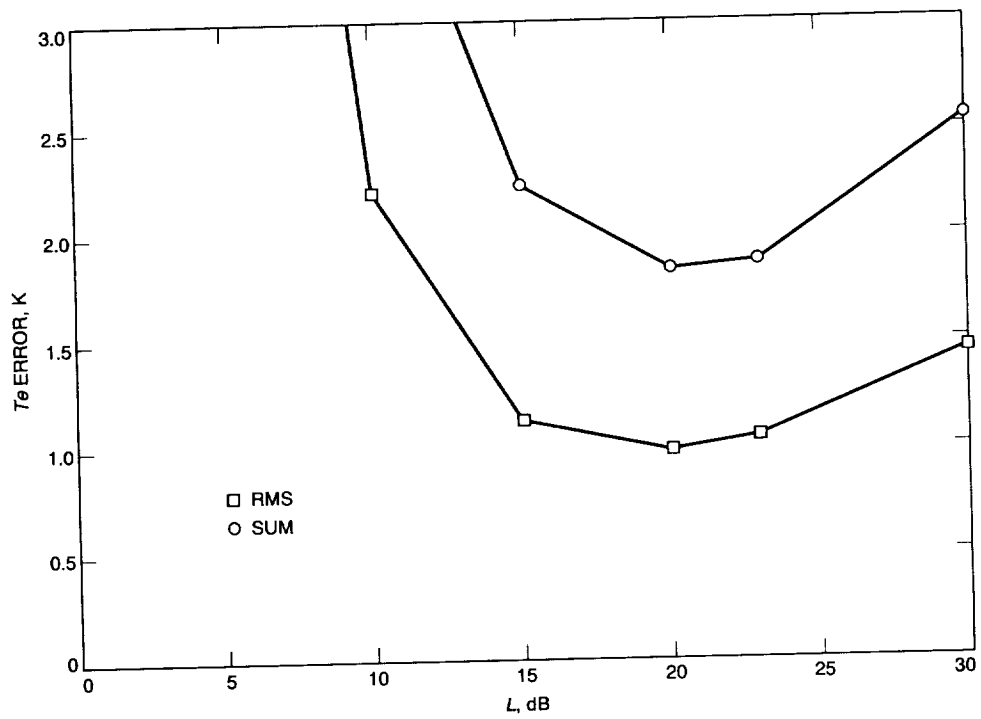


Fig. 4. Plot of the data in Fig. 3.

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INPUT
      T= 300      Tn= 60000      Tp= 2
      DT= .1      DTn= 3000      DTP= .1      Te= 4
      DYLDDB,A= .01 DLDB,A= .01 B,MHZ= 50      DYG= .02
      DYLDDB,B= .01 DLDB,B= .03 T,SEC= 1
      L,DB
      L          0 3 10 15 20 23 30
                1 1.995 10 31.62 100 199.53 1000
RESULTS
----- Te ERROR,K -----
      DL      .013800 .1366 .4133527 .6030 .7862374 .89317 1.1342
      DT      .1      .1 .0501      .01 .0032      .001 .00050 .00010
      DTn 3000 15.2 7.768 1.79 .7712 .449 .37468 .3149
      DTP      .1      0 .0499      .09 .0968      .099 .09950 .0999
      DYLDDB 16.4054 8.356 1.878164 .7655 .3961832 .29695 .17706
      DYN      .086395 .0442 .0101833 .0044 .0025772 .00217 .00197
      DYG      11.7493 6.005 1.384821 .5979 .3503522 .29511 .26658
      SUM      43.5549 22.41 5.576521 2.842 2.084350 1.9621 1.9947
      RMS      25.2634 12.89 2.971278 1.382 1.053227 1.0599 1.2239
NOMINAL CALC
      TL          0 .9976      1.8 1.937      1.98 1.9900 1.998
      Y      198.368 194.6 168.5978 124.0 67.81514 41.130 10.527
      YDB      22.9747 22.89 22.26852 20.93 18.31327 16.142 10.223
      Te          4 4 4 4 4 4 4
ERROR CALC
      L+DL,DB      .01 3.1 10.31 15.46 20.61 23.7 30.91
      L+DL      1.00231 2.042 10.73989 35.16 115.0800 234.42 1233.1
      TL      .004600 1.020 1.813778 1.943 1.982621 1.9915 1.9984
      Te      3.98620 3.863 3.586647 3.397 3.213763 3.1068 2.8658
      T+DT      300.1 300.1 300.1 300.1 300.1 300.1 300.1
      Te      3.9 3.950 3.99 3.997 3.999 3.9995 3.9999
      Tn+DTn      63000 63000 63000 63000 63000 63000 63000
      Te      19.2 11.77 5.79 4.771 4.449 4.3747 4.3149
      Tp+DTP      2.1 2.1 2.1 2.1 2.1 2.1 2.1
      TL      0 1.048 1.89 2.034 2.079 2.0895 2.0979
      Te      4 3.950 3.91 3.903 3.901 3.9005 3.9001
      Y+DYLDDB 23.2145 23.13 22.50120 21.15 18.50640 16.313 10.335
      Y+DYL      209.627 205.6 177.8772 130.4 70.89898 42.785 10.802
      Te      -12.405 -4.36 2.121836 3.234 3.603817 3.7031 3.8229
      Y+DYN      198.425 194.6 168.6455 124.1 67.83433 41.141 10.530
      Te      3.91360 3.956 3.989817 3.996 3.997423 3.9978 3.9980
      Y+DYG      206.303 202.3 175.3417 129.0 70.52775 42.775 10.948
      Te      -7.7493 -2.00 2.615179 3.402 3.649648 3.7049 3.7334
DEFINITIONS
L=ATTEN LOSS      Y=Y FACTOR
DL=DELTA L      DYL=DELTA Y NON-LINEARITY
TL=TEMP CONTRI OF L      DYN=DELTA Y, RADIOMETER NOISE (T,B)
T=INPUT LOAD TEMP      DYG=DELTA Y, RADIOMETER GAIN CHANGE G
DT=DELTA T      Te=LNA NOISE TEMPERATURE
Tp=PHY TEMP OF L      Tn=NOISE SOURCE CONTRIBUTION
DTP=DELTA Tp

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Fig. 5. Supercalc 4 computer program NOISE1ND printout of the analysis of Fig. 1, showing the measurement error as a function of attenuator loss L , dB, and assumed input parameter errors; noise source = 60,000 K. The higher gain change (DYG) than that in Fig. 3 is appropriate for L = small attenuation.

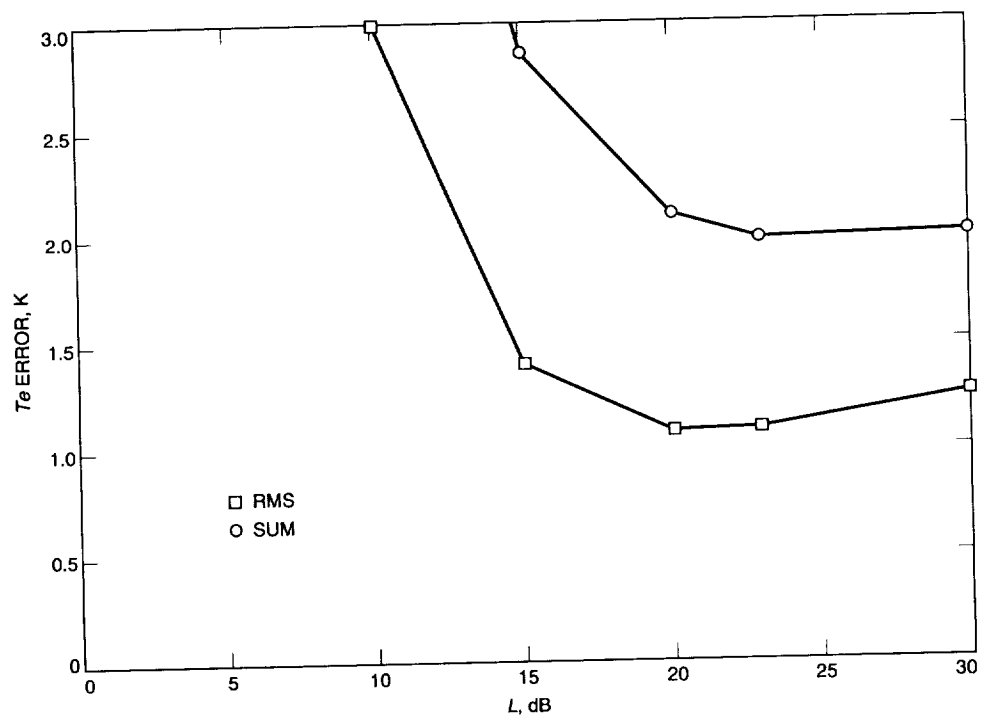


Fig. 6. Plot of the data in Fig. 5.

INPUT

T2=	300	T1=	80	TP=	2	Te=	4
DT2=	.1	DT1=	1	DTP=	.01	DYG=	.01
DYLDL,A=	.01	DLDB,A=	.01	B,MHZ=	50		
DYLDL,B=	.01	DLDB,B=	.03	T,SEC=	1		
L,DB	0	3	10	15	20	23	30
L	1	1.99526	10	31.6228	100	199.526	1000

RESULTS	Te ERROR ,K						
DL	.013800	.136577	.4133527	.603015	.7862374	.893172	1.13423
DT2	.1	.038182	.020497	.0062727	.003848	.0030818	.002905
DT1	1	1.38182	.706154	.1627273	.070107	.0408182	.034062
DTP	.01	0	.004988	.009	.009684	.0099	.009950
DYL	1	.73695	.919911	.2622773	.153609	.1389508	.165092
DYN	.00014	.032817	.017963	.0063487	.005306	.0078186	.012261
DYG	.01	2.25902	1.23585	.4349709	.359467	.5117196	.764731
SUM		5.46259	3.04194	1.294950	1.20504	1.498526	1.88217
RMS		3.16738	1.70048	.6749003	.722143	.9492989	1.18796

NOMINAL

L	NOM	1	1.99526	10	31.6228	100	199.526	1000
TL	NOM	0	.997626	1.8	1.93675	1.98	1.98998	1.998
Y	NOM	3.61905	3.44522	2.594203	1.82170	1.324484	1.17253	1.03620
YDB	NOM	5.58594	5.37217	4.140039	2.60478	1.220466	.691231	.154420
Te	NOM	4	4	4	4	4	4	4

ERROR CALC

L+DL,DB	.01	3.1	10.31	15.46	20.61	23.7	30.91
L+DL	1.00231	2.04174	10.73989	35.1560	115.0800	234.423	1233.10
TL	.004600	1.02044	1.813778	1.94311	1.982621	1.99147	1.99838
Te	3.98620	3.86342	3.586647	3.39699	3.213763	3.10683	2.86577
T2+DT2	300.1						
Te	4.03818	4.02050	4.006273	4.00385	4.003082	4.00290	4.00276
T1+DT1	81						
Te	2.61818	3.29385	3.837273	3.92989	3.959182	3.96594	3.97137
TP+DTP	2.01						
TL	0	1.00261	1.809	1.94644	1.9899	1.99993	2.00799
Te	4	3.99501	3.991	3.99032	3.9901	3.99005	3.99001
Y+DYL,DB	5.65180	5.43589	4.191440	2.64082	1.242671	.708144	.165964
Y+DYL	3.67435	3.49614	2.625089	1.83689	1.331273	1.17710	1.03895
Te	2.26305	3.08009	3.737723	3.84639	3.861049	3.83491	3.56967
Y+DYN	3.62007	3.44619	2.594937	1.82222	1.324858	1.17286	1.03649
Te	3.96718	3.98204	3.993651	3.99469	3.992181	3.98774	3.95118
Y+DYG	3.69143	3.51412	2.646087	1.85814	1.350973	1.19598	1.05692
Te	1.74098	2.76415	3.565029	3.64053	3.488280	3.23527	1.78707

DEFINITIONS

L=ATTEN LOSS

DL=DELTA L

TL=TEMP CONTR OF L

Y=Y FACTOR

DYL=DELTA Y FACTOR NON-LINEARITY

DYN=DELTA Y. RADIOMETER NOISE (T,B)

TP=PHY TEMP OF L

DTP=DELTA TP

Te=LNA NOISE TEMP

T1=COLD LOAD TEMP

DT1=DELTA T1

T2=HOT LOAD TEMP

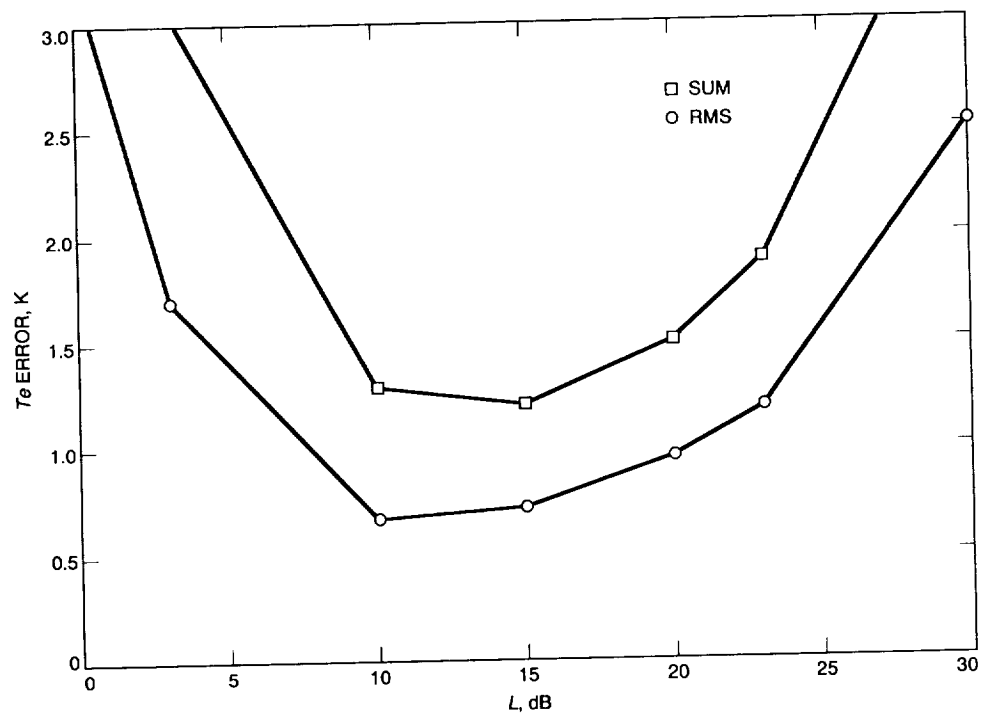


Fig. 8. Plot of the data in Fig. 7.

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INPUT
  T2= 300    T1= 2      Tp= 2
  DT2= .1    DT1= .01   DTP= .01    Te= 4
  DYLDL,A= .01 DLDB,A= .01 B,MHZ= 50  DYG= .02
  DYLDL,B= .01 DLDB,B= .03 T,SEC= 1
  L,DB      0      3      10      15      20      23      30
  L          1 1.99526      10 31.6228      100 199.526      1000
RESULTS
----- Te ERROR ,K -----
  DL      .013800 .136577 .4133527 .603015 .7862374 .893172 1.13423
  DT2     .1 .002013 .002013 .0020134 .002013 .0020134 .002013 .002013
  DT1     .01 .010201 .005213 .0012013 .000518 .0003013 .000251 .000211
  DTP     .01 0 .004988 .009 .009684 .0099 .009950 .00999
  DYLDL   .248935 .213412 .1433149 .113808 .1127445 .133503 .334223
  DYN     .00014 .001731 .001765 .0020381 .002776 .0051096 .008503 .035653
  DYG     .02 .235233 .239670 .2751025 .368672 .6454241 1.00288 2.74862
  SUM     .511914 .603638 .8460230 1.10048 1.561730 2.05027 4.26494
  RMS     .342936 .348854 .5168865 .715963 1.023514 1.34964 2.99240

NOMINAL
  L  NOM  1 1.99526      10 31.6228      100 199.526      1000
  TL  NOM  0 .997626      1.8 1.93675      1.98 1.98998      1.998
  Y   NOM 50.6667 25.8923 5.966667 2.57060 1.496667 1.24892 1.04967
  YDB  NOM 17.0472 14.1317 7.757318 4.10034 1.751251 .965357 .210514
  Te  NOM  4      4      4      4      4      4      4

ERROR CALC
  L+DL,DB      .01      3.1      10.31      15.46      20.61      23.7      30.91
  L+DL         1.00231 2.04174 10.73989 35.1560 115.0800 234.423 1233.10
  TL           .004600 1.02044 1.813778 1.94311 1.982621 1.99147 1.99838
  Te           3.98620 3.86342 3.586647 3.39699 3.213763 3.10683 2.86577
  T2+DT2 300.1
  Te          4.00201 4.00201 4.002013 4.00201 4.002013 4.00201 4.00201
  T1+DT1 2.01
  Te          3.98980 3.99479 3.998799 3.99948 3.999699 3.99975 3.99979
  TP+DTP 2.01
  TL           0 1.00261      1.809 1.94644      1.9899 1.99993 2.00799
  Te           4 3.99501      3.991 3.99032      3.9901 3.99005 3.99001
  Y+DYLDL,DB  17.2277 14.2830 7.844891 4.15134 1.778763 .985010 .222619
  Y+DYLDL     52.8165 26.8103 6.088203 2.60096 1.506178 1.25459 1.05260
  Te          3.75106 3.78659 3.856685 3.88619 3.887256 3.86650 3.66578
  Y+DYN       50.6810 25.8996 5.968354 2.57132 1.497090 1.24928 1.04996
  Te          3.99827 3.99824 3.997962 3.99722 3.994890 3.99150 3.96435
  Y+DYG       52.6933 26.9280 6.205333 2.67342 1.556533 1.29888 1.09165
  Te          3.76477 3.76033 3.724898 3.63133 3.354576 2.99712 1.25138

DEFINITIONS
  L=ATTEN LOSS                      Tp=PHY TEMP OF L
  DL=DELTA L                        DTP=DELTA Tp
  TL=TEMP CONTR OF L                Te=LNA NOISE TEMP
  Y=Y FACTOR                        T1=COLD LOAD TEMP
  DYLDL=DELTA Y FACTOR NON-LINEARITY DT1=DELTA T1
  DYN=DELTA Y, RADIOMETER NOISE (T,B) T2=HOT LOAD TEMP
  DYG=DELTA Y, RADIOMETER GAIN DELTA G DT2=DELTA T2

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Fig. 9. Supercalc 4 computer program NOISE1LD printout of the analysis of Fig. 2, showing the measurement error as a function of attenuator loss L , dB, and assumed input parameter errors; $T_1 = 2$ K and $T_2 = 300$ K.

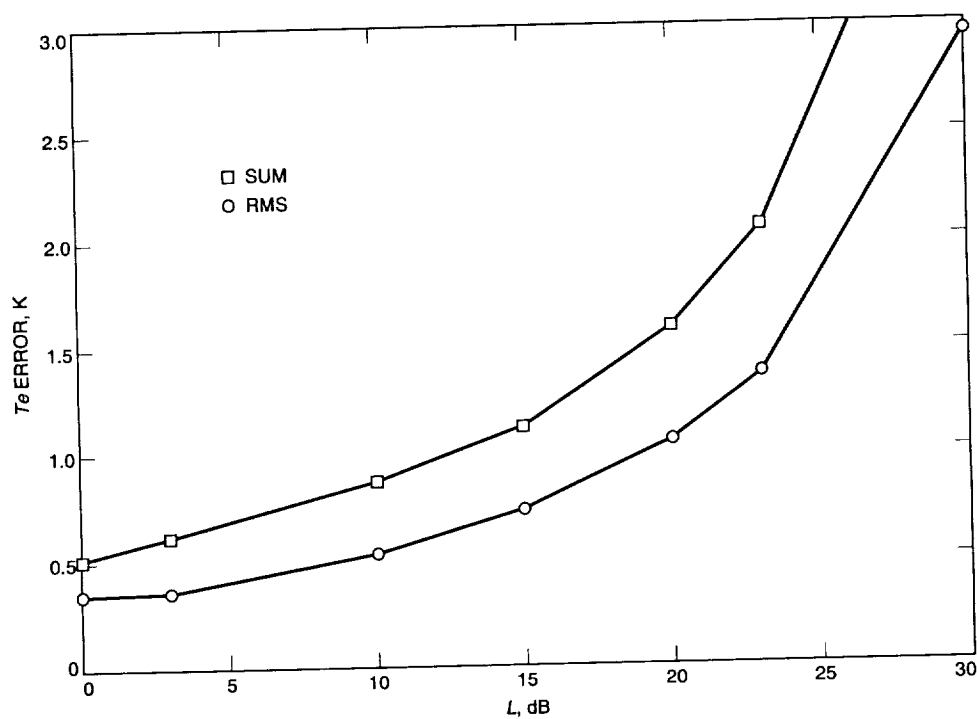


Fig. 10. Plot of the data in Fig. 9.

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INPUT
T2= 300 T1= 2 Tp= 2
DT2= .1 DT1= .01 DTP= .01 Te= 4
DYLDB,A= .01 DLDB,A= .01 B,MHZ= 50 DYG= .01
DYLDB,B= .01 DLDB,B= .03 T,SEC= 1
L,DB 0 3 10 15 20 23 30
L 1 1.99526 10 31.6228 100 199.526 1000

RESULTS
----- Te ERROR ,K -----
DL .013800 .136577 .4133527 .603015 .7862374 .893172 1.13423
DT2 .1 .002013 .002013 .0020134 .002013 .0020134 .002013 .002013
DT1 .01 .010201 .005213 .0012013 .000518 .0003013 .000251 .000211
DTP .01 0 .004988 .009 .009684 .0099 .009950 .00999
DYL 248935 .213412 .1433149 .113808 .1127445 .133503 .334223
DYN .00014 .001731 .001765 .0020381 .002776 .0051096 .008503 .035653
DYG .01 .119968 .122277 .1407786 .190179 .3410558 .547170 1.78262
SUM .396649 .486245 .7116991 .921992 1.257362 1.59456 3.29895
RMS .276880 .281441 .4596835 .642536 .8644813 1.05601 2.13946

NOMINAL
L NOM 1 1.99526 10 31.6228 100 199.526 1000
TL NOM 0 .997626 1.8 1.93675 1.98 1.98998 1.998
Y NOM 50.6667 25.8923 5.966667 2.57060 1.496667 1.24892 1.04967
YDB NOM 17.0472 14.1317 7.757318 4.10034 1.751251 .965357 .210514
Te NOM 4 4 4 4 4 4 4

ERROR CALC
L+DL,DB .01 3.1 10.31 15.46 20.61 23.7 30.91
L+DL 1.00231 2.04174 10.73989 35.1560 115.0800 234.423 1233.10
TL .004600 1.02044 1.813778 1.94311 1.982621 1.99147 1.99838
Te 3.98620 3.86342 3.586647 3.39699 3.213763 3.10683 2.86577
T2+DT2 300.1
Te 4.00201 4.00201 4.002013 4.00201 4.002013 4.00201 4.00201
T1+DT1 2.01
Te 3.98980 3.99479 3.998799 3.99948 3.999699 3.99975 3.99979
TP+DTP 2.01
TL 0 1.00261 1.809 1.94644 1.9899 1.99993 2.00799
Te 4 3.99501 3.991 3.99032 3.9901 3.99005 3.99001
Y+DYL,DB 17.2277 14.2830 7.844891 4.15134 1.778763 .985010 .222619
Y+DYL 52.8165 26.8103 6.088203 2.60096 1.506178 1.25459 1.05260
Te 3.75106 3.78659 3.856685 3.88619 3.887256 3.86650 3.66578
Y+DYN 50.6810 25.8996 5.968354 2.57132 1.497090 1.24928 1.04996
Te 3.99827 3.99824 3.997962 3.99722 3.994890 3.99150 3.96435
Y+DYG 51.68 26.4101 6.086 2.62201 1.5266 1.27390 1.07066
Te 3.88003 3.87772 3.859221 3.80982 3.658944 3.45283 2.21738

DEFINITIONS
L=ATTEN LOSS Tp=PHY TEMP OF L
DL=DELTA L DTP=DELTA Tp
TL=TEMP CONTR OF L Te=LNA NOISE TEMP
Y=Y FACTOR T1=COLD LOAD TEMP
DYL=DELTA Y FACTOR NON-LINEARITY DT1=DELTA T1
DYN=DELTA Y, RADIOMETER NOISE (T,B) T2=HOT LOAD TEMP
DYG=DELTA Y, RADIOMETER GAIN DELTA G DT2=DELTA T2

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Fig. 11. Supercalc 4 computer program NOISE1LD printout of the analysis of Fig. 2, showing the measurement error as a function of attenuator loss L , dB, and assumed input parameter errors; $T_1 = 2$ K and $T_2 = 300$ K. The lower gain change (DYG) than that in Fig. 9 is appropriate for case 5, $L = 10$ dB.

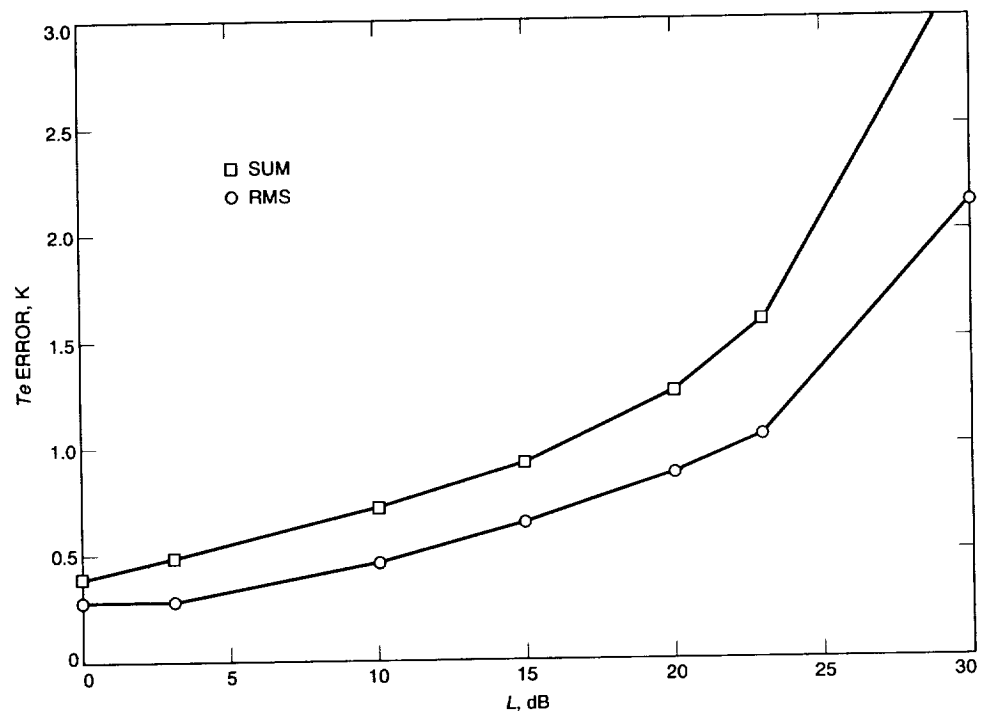


Fig. 12. Plot of the data in Fig. 11.